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Potential for respirable quartz exposure from North Carolina farm soils

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Sandy-loam soils from six active farms in the coastal plains of North Carolina (USA) were analyzed for aerodynamic equivalent diameter and quartz content and compared with results to similar analyses of clay soils of the Piedmont and sandy soils from the sand hills of North Carolina to see whether respirable quartz content varies with soil type. The respirable fraction of sandy loam-soils averaged 0.04 (SD 0.02) versus 0.13 (SD 0.03) for clay soils and 0.04 (SD 0.03) for sandy soils. Quartz content in the 4.25 µm fraction of sandy-loam soils averaged 15.2 (SD 4.1) % versus 2.2 (SD 0.8) % in clay soils and 29.0 (SD 11.1) % in sandy soils. The mass of respirable quartz in sandy-loam soils averaged 0.7 (SD 0.4)% versus 0.3 (SD 0.1)% in clay soils and 1.0 (SD 0.4) % in sandy soils. These results suggest that, during dusty farm activities, there is a potential for greater respirable quartz exposures associated with work with sandy or sandy-loam soils than from work with clay soils.

Key terms agriculture, quartz, respirable fraction, soil analysis.

Exposures to respirable quartz in such industries as hard rock mining, construction, pottery, silica flour mining and milling, and sand blasting carry with them an increased risk of silicosis (1, 2). More recently, several reports have identified a risk of respiratory disease, including pneumoconiosis, among farm laborers. Between 1968 and 1988 in the United States, in multiple cause of death listings where there was any mention of silicosis, farming was mentioned as the third most common occupation (3). The processing of tobacco leaves was the industry with the third highest incidence rate of reported occupational pulmonary diseases for 1989 (3). Sherwin et al (4) described a series of five cases of progressive respiratory failure and death among five nonsmoking California table grape harvesters for whom lung tissue analysis showed chronic inflammation and fibrosis associated with particle deposition. Analysis of the particles disclosed that 5—10% was silicon dioxide. Analysis of the < 5 µm fraction of dirt from the involved fields showed similar elemental distributions to those of the particles found in the lungs. Popendorf et al (5, 6) measured the respirable quartz exposures of California harvesters of citrus, peach, and grape crops. Respirable quartz exposures ranged from 7 to 105 $\mu g \cdot m^{-3}$, and the quartz content of the respirable dusts ranged from 1 to 12%, being highest among the table grape harvesters. Individual cases of pulmonary fibrosis and silicosis have been reported for farmers with quartz levels ranging from 14 to 58% in the mineral dust found in lung tissue (7, 8). Finally, Carlson & Petersen (9) found an excess rate of death from respiratory disease among farm workers compared with farm owners-managers in California.

As part of an effort to define the potential for respirable quartz exposure during farming further, we completed a study of respirable silica in bulk clay and sandy farm soils (10). This study suggested that, for sandy farm soil, quartz exposure can approach the levels found in hard rock mining. We have now extended this study to the evaluation of sandy-loam soils.

Materials and methods

Sandy-loam samples were collected with a stainless steel scoop and stored in polyethylene bags prior to the analysis. No attempt was made to assure that the samples were representative of any particular tilled field. Soils were prepared by drying in an oven at 279°F (137°C) for 2 h. Only clay soils had to be further processed by crushing lumps. Only the particles passing through a 45-µm mesh sieve (and thus likely to be entrained in air) were analyzed further.

Aerodynamic equivalent diameter (AED) is a property of particles that has been directly related to the probability of deposition in the lungs (11). The American Conference of Governmental Industrial Hygienists (12) defines respirable fraction or mass as that portion which penetrates a separator with a size collection efficiency described by a cumulative log-normal function with a median AED of 4.25 µm and a geometric standard deviation of 1.5 µm. Particles settle according to Stokes' Law such that the mass of particles that settle in a given time is proportional to the AED (13). The AED is determined by sampling particle mass at 5 cm below the surface of the Andreasen pipette every 10 min (13—16). The AED is plotted as a cumulative size distribution on log-normal paper with a regression analysis (Quattro Pro, Novell, Utah, United States) from which respirable fraction is determined by interpolation.

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We analyzed samples from six farms growing sweet potatoes or peanuts in three eastern counties of North Carolina's coastal plain. Quartz was analyzed using the carbonate fusion method of Dobreva (17) as modified by Stopford (15). Although crystalline silica and quartz were used interchangeably in the report for convenience, this method does not differentiate between various crystalline polymorphs of silica. Results using this method agree well with the results of analyses by X-ray diffraction (18). This method has the advantage over X-ray diffraction because there are no interferences by silicates, feldspar, or iron (15, 19).

Results

Particle analyses of 45-μm dusts. As can be seen in table 1, the Andreasen pipette analyses of dried dirt that is sieved to 45 μm or less showed that the geometric mean AED ranged from 35.7 to 117.8 (mean 82.6) μm. The samples followed a log-normal distribution with geometric standard deviations of the median values ranging from 4.5 to 7.2 (mean 5.4) μm. The respirable fractions ranged from 0.02 to 0.07 (mean 0.04, SD 0.02).

Quartz analyses. Quartz analyses of ≤ 45-μm particle size dusts (table 2) showed levels ranging from 25.4 to 56.3 (mean 44.6) %. The quartz content in the respirable fraction of these samples was consistently less, ranging from 9.1 to 21.3 (mean 15.2) %. The mass of respirable quartz, calculated by multiplying the respirable fraction times the percentage of quartz in the 4.25-μm fraction, ranged from 0.27 to 1.49 (mean 0.65, SD 0.43) %.

Discussion

This study has shown that quartz levels in the respirable fraction of sandy-loam soils from farms growing root crops range from 9.1 to 21.3%. These levels are generally higher than the 1 to 12% quartz found by Popendorf et al (5, 6) in dusts generated during the manual harvesting of fruit crops and levels from 0.85 to 17.5% found in tractor air filters at the end of the growing season (20). In the latter study, 50—97% of the dust in the filters had an AED of < 5 μm. This study also suggests that actual entrained dust may include a larger percentage of respirable dust than the 45-μm sieve cut used in our study. As can be seen in table 3, quartz levels in sandy-loam soil are intermediate to those found in clay and sandy soils.

Brantley (16) and Reist & Creed (13) found that measurements of respirable fraction made with an Andreasen sedimentation pipette correlate well with measurements of respirable fraction in a dust cloud. The percentage of respirable quartz of a soil can thus be used to estimate the respirable quartz levels expected to be found in air under certain work conditions. Total airborne dust levels range from 5 to 70 mg · m^{-3} during manual harvesting activities (6) and from 10 to 200 mg · m^{-3} during mechanized farm activities (21). These values suggest that airborne respirable quartz levels could be on the order of 15 to 600 μg · m^{-3} during the farming of clay soils, 35 to 1400 μg · m^{-3} during the farming of sandy-loam soils, and 50 to 2000 μg · m^{-3} during the farming of sandy soils.

However, the ability of respirable-sized quartz particles in a soil to be aerosolized would likely depend on factors such as the amount of binding to the clay matrix in a soil (22) and the amount of soil moisture. Only clay soil samples require mechanical crushing of particles to produce a dust that could pass through a 45-μm sieve. These soils would also have to be crushed in the field by mechanized farm activities to release respirable-sized quartz particles. Soil moisture would also play a factor; sandy soils would be less likely to retain moisture than clay or sandy-loam soils. In our study soil moisture levels averaged 10.1 (SD 3.9) % for clay soils, 2.5 (SD 3.6) % for sandy-loam soils, and 0.9 (SD 0.5) % for sandy soils.

Our study also found that the percentage of quartz in the respirable fraction of each sample was consistently less than in the 45-μm cut of each soil in that the quartz particles tended to be larger than other associated soil particles. In clay soils respirable quartz was found to make up 0.96 (SD 1.16) % of the total quartz present versus 1.52 (SD 0.70) % in sandy soils and 1.39 (SD 0.66) % in the sandy-loam soils analyzed in this study. This relationship has also been seen by others (23). However, there is no close relationship between total quartz levels in soil and those found in the respirable fraction (5).

Exposure to respirable quartz in soil can also occur during the processing of crops. Farant & Moore (24) found respirable dust levels as high as 12 700 μg · m^{-3}, and the quartz content of the respirable dust ranged as high as 6.1% during the processing of grains. Williams (25) found respirable quartz levels to range from 470 to 1 170 μg · m^{-3} during the processing of tobacco. Barish & Nicas (26) found exposures to respirable quartz as high as 400 μg · m^{-3} among processors of root crops. Since farming is a seasonal activity, farm laborers would have less of a risk of developing silicosis than farmers engaged in the daily processing of crops contaminated with soil or workers exposed to respirable quartz particles in other industries (26).

Table 1. Particle size analyses of 45-μm sieve dusts.

Farm	Geometric mean aerodynamic diameter (μm)	Geometric standard deviation (μm)	Respirable fraction
a	35.7	4.5	0.07
b	73.3	4.6	0.03
c	95.7	5.8	0.03
d	106.2	7.2	0.05
e	117.8	5.7	0.02
f	66.8	5.1	0.04

Table 2. Quartz content of 45-μm and 4.25-μm soil dusts.

Farm	Quartz in 45-μm sieve dust (%)	Quartz in 4.25-μm fraction (%)	Respirable quartz (%)
a	56.3	21.3	1.49
b	49.9	9.1	0.27
c	46.2	16.2	0.49
d	54.3	18.5	0.92
e	25.4	14.7	0.29
f	35.8	11.3	0.45

Table 3. Comparison of quartz content of soil dusts according to soil type.

Soil type[a]	Quartz in 4.25-μm fraction (%)		Respirable quartz (%)	
	Mean	SD	Mean	SD
Clay soils (N = 6)	2.2	0.8	0.3	0.1
Sandy-loam soils (N = 6)	15.2	4.1	0.7	0.4
Sandy soils (N = 8)	31.6	9.3	1.0	0.4

[a] N = number of farms.

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